MODELING AND MITIGATION OF BLAST EFFECTS
WITHIN PROTECTIVE STRUCTURES

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ABSTRACT

Computational methods are currently available to perform vulnerability assessments of conventional structures and fixed facilities that are exposed to the effects of large-yield blast events. However, the same capabilities do not exist for expeditionary structures and field fortifications, which are integral parts of current US military base camps. Therefore, the United States Army Corps of Engineers (USACE), Engineer Research and Development Center (ERDC), has begun a research and development initiative directed towards developing this type of vulnerability assessment capability for field fortifications. As a part of the experimental program, attention will also be focused on identification of field expedient methods to modify these structures for the purpose of further protection from blast effects.

Initial efforts, begun in FY 2004, are focused on methodology development and gathering of a representative experimental data set that would be required to support computational assessments. The experimental processes used to gather data are tri-fold, and include high-performance computing simulations, scaled modeling and full scale validations. The results of initial activities in each of these areas are presented herein.

1. INTRODUCTION

As a part of enhancing protective capabilities for US military forces, the United States Army Corps of Engineers (USACE), Engineer Research and Development Center (ERDC) is currently involved in a research and development initiative directed towards the evaluation of blast effects on field fortifications. Specifically, this work is aimed toward the development of a rapid vulnerability assessment tool that will allow soldiers to evaluate survivability levels of field fortifications – based on the internal pressure-impulse environment - when exposed to the effects of a large blast hazard such as a car bomb. Vulnerability assessments of fixed facilities in the blast environment can currently be performed in codes such as ERDC's ATPlanner, based on structural response and debris hazard generation. However, the capability to perform similar assessments for field fortifications based on internal pressure conditions does not exist.

To develop this type of computationally based vulnerability assessment tool, algorithms must be established which take into consideration structure geometry, charge size and standoff, and orientation of the charge with respect to the structure. In January 2004, ERDC began initial experimental activities directed at establishing a methodology to define the influence of each of these variables on the internal pressure environment. This work is expected to continue through FY 2005.

To generate the necessary information, a multi-thrust experimental program has been devised. At the core of this program will be the use of numeric capabilities such as high-performance computing with hydrocodes. The hydrocode calculations will establish the primary data set relating range and charge location to internal conditions. However, to verify the accuracy of the numeric simulations, some amount of physical modeling must also be included. To that end, validation experiments will be performed by means of both scaled modeling and full-scale validations. For the sake of cost effectiveness, the scaled modeling will be used as the primary means of physical validation. Scaled model evaluations of the structures can be performed for relatively low cost at local facilities, and theoretically should show good agreement to full-scale results. However, to fully verify the accuracy of both the numeric and scaled model solutions, select full-scale validations must also be conducted. Because these validations are significantly more expensive than the other two experimental activities, implementation is carefully considered so that they are used only to generate key data points for comparison to the other two methodologies.

At this time, structures included for evaluation in the program were chosen from a family of Hesco Bastion based field fortifications. These structures were developed by ERDC, in conjunction with the US Army Engineer School, to address specific Army force protection needs. Included in this family of positions are structures such as observation posts and personnel bunkers, which are likely candidates for exposure to severe overpressure environments. With method of employment being the primary selection criterion, four of the pre-designed structures were selected for inclusion in the initial program. These structures include two observation posts and two personnel bunkers. As an example of the Hesco Bastion structures, a personnel bunker is shown in Figure 1.

In the consideration of blast effects on field fortifications, two issues should be of concern. One is the blast loading to the structure and the ensuing dynamic response. The other, assuming the structure is not destroyed, is the internal pressure

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environment experienced by occupants. The Hesco Bastion structures are constructed with high mass, soil filled walls that generate high inertial resistance to impulsive loading. Due to this, it is believed that internal pressure conditions within the structures will be the limiting factor when considering position survivability – not the positions' structural integrity. Thus, for the purpose of this effort, only internal pressure-impulse conditions are considered, and the structural components are assumed to be sufficient to withstand dynamic loads over the range of consideration.

Figure 1. Hesco Bastion personnel bunker

In addition to the primary objective of developing scaled-range/internal effects relationships, this research program also presents an opportunity to evaluate the effects of structure modifications on shock wave propagation. Upon establishment of baseline performance, it would be a simple process to implement basic modifications for the purpose of evaluating their effects on the survivability level of occupants. These modifications may include actions as simple as sandbagging the firing portals or hanging cloth over the doorway, and have been included in the experimental activities for evaluation. Dependent upon the results, these could be included as selective upgrade options in the ATPlanner assessment.

The objective of preliminary experimental activities was to generate an abbreviated set of internal pressure records that were obtained from numeric modeling, scaled modeling, and a full-scale validation. This information would be utilized to evaluate the data generation process, make initial comparisons between the results of each experimental component, and assist in defining the most effective and efficient process to obtain the necessary remaining information. Upon review of these results, modeling and simulation work would then continue to develop the full data set required to support the computational vulnerability assessment.

This research is being conducted as a part of STO IV.EN.2002.03, "Protection Against Terrorist and Conventional Attacks in Contingency Environments."

2. HYDROCODE SIMULATION

The Second-order, Hydrodynamic, Automatic Mesh Refinement Code (SHAMRC) has been selected to perform numeric calculations. SHAMRC, is a hydrodynamic, finite difference code developed for the purpose of modeling air blast related events such as bare high explosive detonations, detonation of cased munitions and shock tube air compression/expansion problems. SHAMRC will support the employment of logical automatic mesh refinement, which automatically performs refined mesh calculations in high gradient zones. By providing this function, enhanced fidelity can be generated in the model results where necessary without exhaustively increasing the computational requirements.

The structure selected for initial simulation exercises was a large observation post. This structure was chosen because of its applicability in current military operations and its likely exposure to large blast threats. Generally speaking, the structure has overall dimensions of 14 ft by 18 ft and inside dimensions of 7 ft by 10.5 ft. Five large openings are present as viewing/firing portals, and one entryway is located near the rear. The position was modeled in SHAMRC as a completely non-responsive structure, which allowed all of the walls to act as perfect reflecting surfaces for shock wave propagation. A completed in-place observation post is shown in Figure 2.

Figure 2. Large observation post

To establish a benchmark comparison between the SHAMRC results and scaled model results, the first calculations were performed as direct simulations of the scaled model setup. In other words, instead of simulating the explosive event at full scale in SHAMRC, it was conducted at the same structure and charge size as was performed in the scaled physical experiment. The purpose for doing this is that it will provide the most direct comparison between the two methodologies of predicting internal conditions. As a result, if agreement is seen between the two methods then the only extension that must be made will be the application of Hopkinson's scaling laws. And based on extensive prior applications of this scaling technique, it is expected that the results seen at scale level will be closely replicated in full-scale events.

Scaled modeling efforts were expected to be conducted at 1/8th scale, and thus, simulation of the event was conducted at the same. The explosive charge utilized in the model was selected to be representative of a large-charge threat such as a car bomb. The charge was detonated in front of the structure such that the shock front engulfed it from front to back.

A clear advantage of utilizing computational tools for these types of activities is the capability to generate spatial load data for a given event, as compared to the point-source data typically gathered in physical experiments. With this information, especially in regard to shock wave phenomena, great insight can be gained concerning wave flow and interaction. It is possible to obtain an understanding of the root conditions creating the observed effects, and methods to manipulate the results can be evaluated with direct knowledge of their impact on the system. As an example of this, pressure contours generated by SHAMRC are presented for three time steps during engulfment of the structure. The images depict pressure contours on two surfaces. One surface is a vertical slice through the center of the structure and the other is a horizontal slice at the floor. From these images, the reduction of pressures inside the structure, reflections from the inner walls, and zones of potential wave interaction can be seen.

The first image, shown in Figure 3, depicts the shock front just before impinging upon the structure. In this image, the "shocked up" condition at the wave front is seen in the higher intensity yellow zone. In Figure 4, the shock wave has progressed across half of the structure and has begun to expand into the position cavity. Seen are zones of pressure spikes generated by reflections and low pressure zones generated by abrupt changes in volume and geometry. Lastly, Figure 5 depicts conditions just before complete engulfment. Again, the reduction in pressures below that which exists externally is seen. Also, the shock wave has begun to propagate into the doorway to begin interacting with the initial wave traveling through the body. With this information it is now possible to evaluate what modifications may be necessary to enhance performance. An example of this, and a modification that has been evaluated, is placing a shielding cloth over the door to disrupt wave interaction as the shock enters through it.
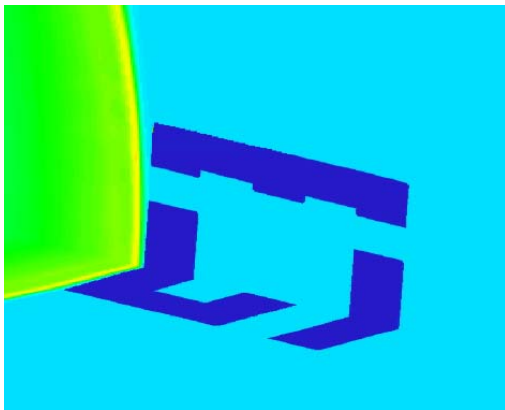

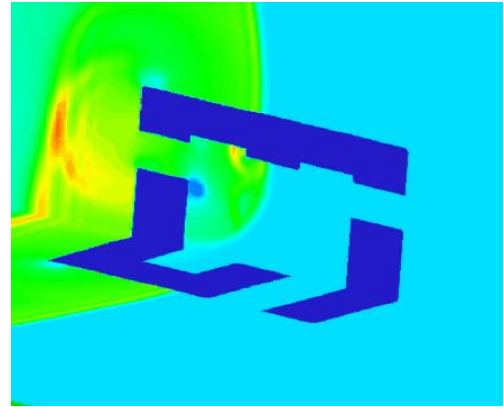Figure 3. Shock wave just before impinging upon structure

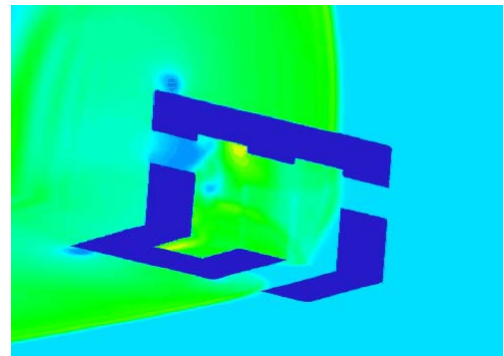Figure 4. Shock wave propagated across ½ of structure

Figure 5. Structure nearly engulfed by shock wave

A more detailed discussion of the SHAMRC predictions is given in Section 3. However, to provide an indication of the modeling results, Figure 6 shows pressure-time histories from two locations inside the structure as well as a theoretical free field record at the same standoff. The measuring locations inside the structure are approximately chest high and represent one point near the front of the structure and one point near the rear.
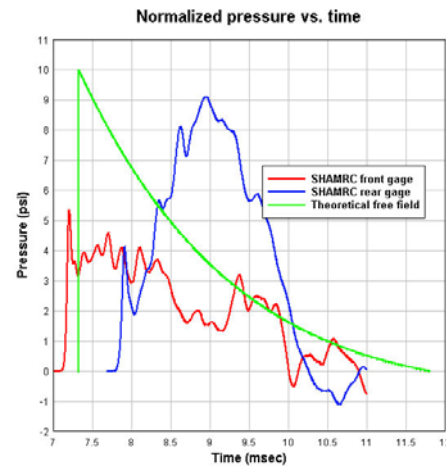

Figure 6. Internal pressure vs. theoretical free field

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Due to critical technology protection requirements, specific data cannot be presented in this forum. Therefore, the records presented in Figure 6 have been normalized such that the free field peak pressure recording is 10 psi.

As seen in Figure 6, both gages showed a reduction in peak pressure as compared to the free field. However, a drastic difference was seen between the front and rear gages. The reason is wave interaction, and the implications are further discussed in the following section.

3. SCALED MODELING

For the purpose of providing a cost effective means to validate SHAMRC results, a series of scaled model experiments were conducted in the spring of 2004. The experiments were conducted at the ERDC Big Black test site and included modeling of four protective structures. Each structure was exposed to the effects of between seven and nineteen explosions, and the internal pressure environment was characterized for each.

3.1 Experimental Configuration

The test scale was established as $1/8^{th}$. This was chosen as a balance between test bed size requirements, limitations on explosive weights, and limitations on scaling applicability. At this scaling factor, charge standoffs were expected to approach 20 ft, and it was thus necessary to construct an approximate 40 ft square test bed. To address instrumentation requirements, an 8 ft square steel reaction table was constructed at the center of the test bed. The table allowed for access to the bottom of the structures and provided a surface for mounting instrumentation hardware. A 4 ft tall retaining wall was then constructed beyond the limits of the table to form an overall 40 ft by 40 ft area, and the space between was filled with sand. With the sand placed to an elevation flush with the top of the table, a surface was provided to simulate shock wave flow over the ground surface between any charge location and the structure.

The target data expected from these experiments was pressure-time histories recorded at specific locations within the positions. The locations were chosen based on the resulting data's applicability to survivability assessments and their capability to generate an overall picture of the internal pressure environment. Note that the gage locations also coincided with those points where pressure-time histories were generated by SHAMRC, and thus comparisons could be made between the two.

Because of the objectives driving the selection of gage location, it was not acceptable to only mount gages in the walls of the structures. Rather, it was also necessary to also make measurements of the pressure environment in "free air" – thus better determining what conditions an occupant might experience. Therefore, two types of gage mountings were included. For those gages intended to measure the reflected pressure conditions at wall surfaces, they were mounted to

brackets placed inside the wall and the sensing tip was placed flush with the wall face. To measure "free air" conditions, threaded rods were used to span between supports embedded in the walls, and gages were mounted directly to the rods. In this manner, the "free air" gage locations could be adjusted vertically and horizontally such that they could be placed anywhere within the envelope of the structure. A typical internal gage arrangement is shown in Figure 7. Note the "free air" gages mounted on the threaded rod and the gages mounted within the wall.
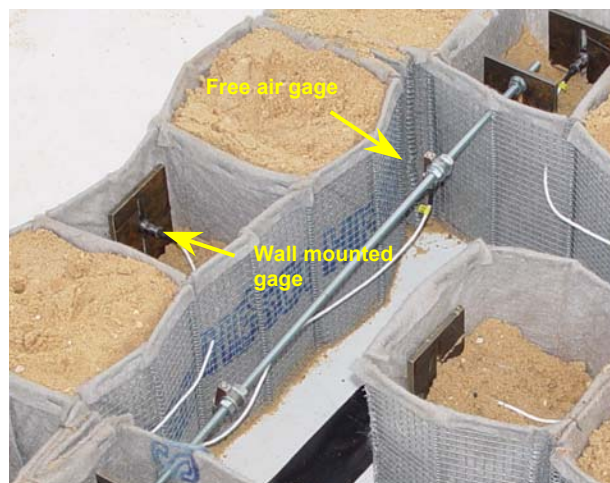

Figure 7. Large observation post internal gage arrangement

3.2 Sample Results

Due to the extensive data generated, it would be impossible to present all of the findings here, or even a reasonable portion thereof. Therefore, presented will be typical findings from evaluation of a single structure. This will provide an indication of the experimental methodology and the type of data gathered, and will allow for comparison to the numeric predictions.

The first structure modeled in the experimental series was the large observation post. Overall scaled dimensions of the structure were 26 in. by 21 in. The position was constructed from scaled Hesco Bastion baskets produced by the manufacturer, and fourteen gages were utilized to characterize the pressure environment. Sand infill was used for the walls and roof.

The entire experimental series included detonation of nineteen charges at various locations. The charge location matrix was utilized to evaluate issues such as results repeatability, the influence of charge position on internal pressures, and the influence of structure modifications on internal pressures.

Prior to conduct of the experiment, concern was given to differing ground surface conditions between SHAMRC and the physical experiment. The ground surface in SHAMRC was considered to be a perfectly reflective, unyielding surface. As

a result, upon detonation of the charge the shock front was not affected by the surface's deformation. However, in the physical experiment the ground surface was sand, in which theoretically as much as 15 percent of the explosive energy could be dissipated through cratering. To minimize this effect a piece of plywood was placed beneath the charge for the purpose of increasing the reflectivity of the underlying surface. Although this did not create the ideal reflecting plane, it did help to minimize reduction of the shock front peak. A typical experimental setup, with charge in place over the plywood, is shown in Figure 8.

Figure 8. Large observation post scaled experiment

As with the data presented from SHAMRC, critical technology protection requirements dictate that specific data concerning internal pressure conditions not be presented. Therefore, as before the pressure records have been normalized to generate a peak free field pressure of 10 psi, or peak free field impulse of 10 psi-msec, at a standoff distance equal to that between the charge and the structure. With this normalization technique, it will be easy to make comparisons between free field conditions and the internal environment without divulging detailed data.

The first two charges were detonated in the same location to evaluate reliability of the experimental setup and repeatability of the experiment. A pressure-time history from each explosion is shown in Figure 9. As is seen, there is good agreement between the two records.

For comparison to the results of SHAMRC, three measurement locations have been chosen for presentation. These were selected to provide a representative comparison of the pressure environment throughout the structure, and include: 1) a measuring point on the floor of the structure, 2) a measuring point in the "free air" near the front of the structure, and 3) a point on the back wall of the structure. For each location, normalized pressure and impulse records are given. These are shown in Figures 10 through 15.
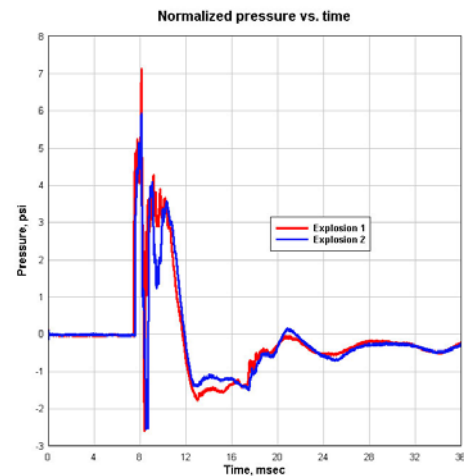

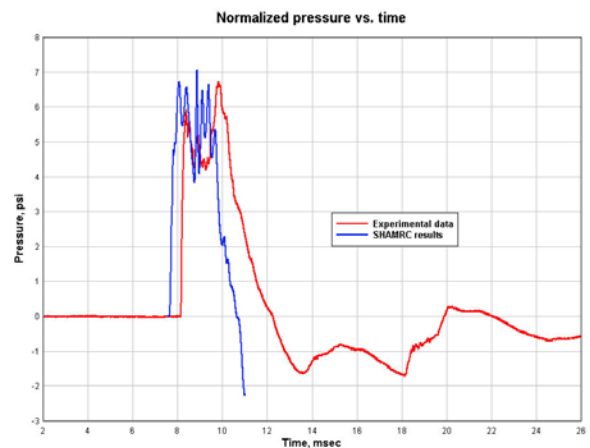Figure 9. Comparison of experimental pressure records
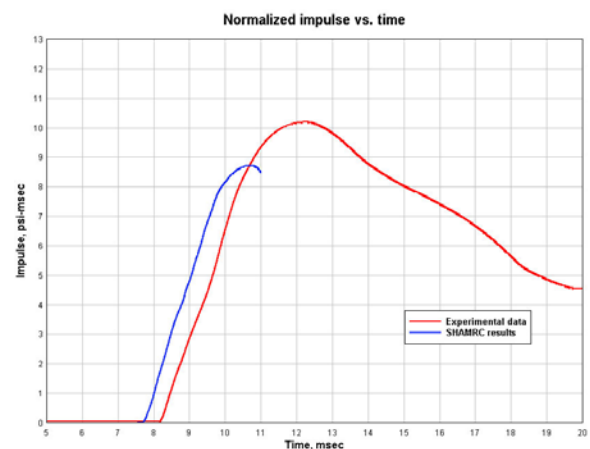

Figure 10. Floor gage, normalized pressure vs. time

Figure 11. Floor gage, normalized impulse vs. time
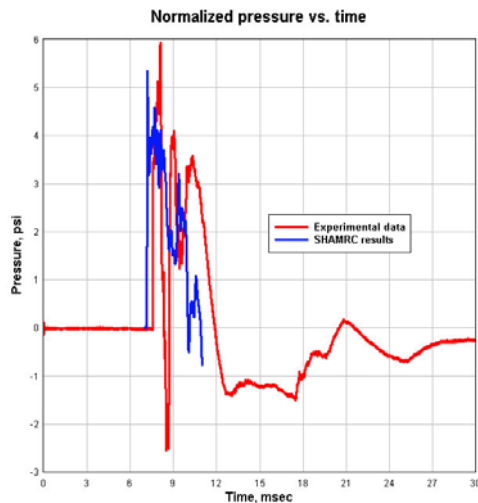
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Figure 12. Free air gage, normalized pressure vs. time
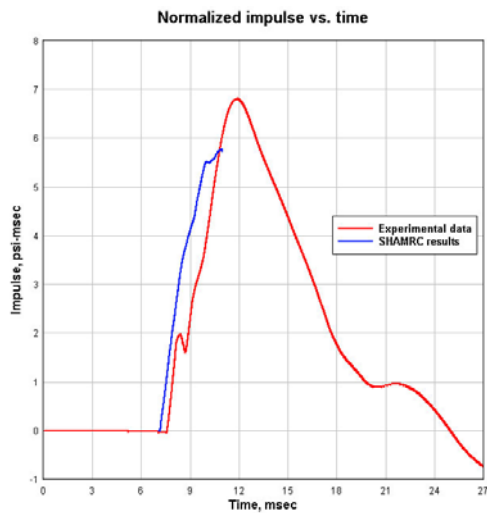

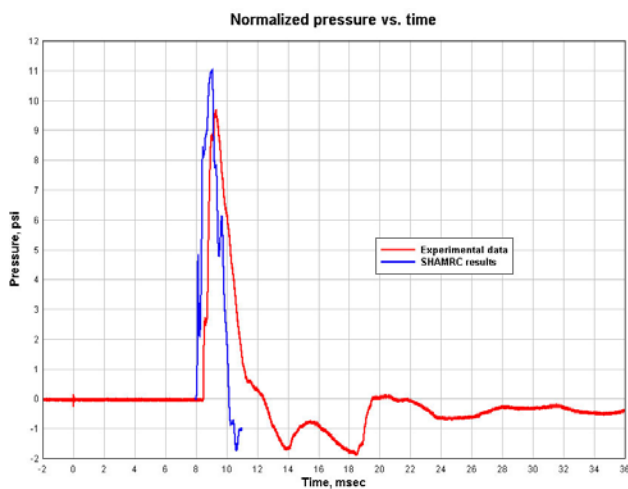Figure 13. Free air gage, normalized impulse vs. time

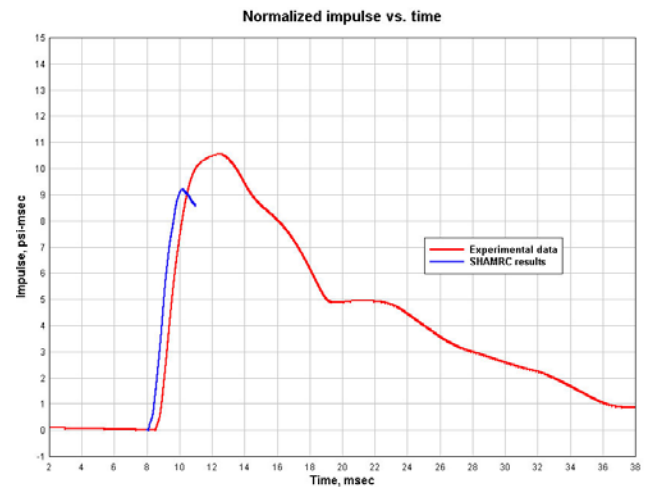Figure 14. Wall gage, normalized pressure vs. time

Figure 15. Wall gage, normalized impulse vs. time

From the data above, two observations can be made. One is in regard to the data's implications on survivability and the other is in regard to comparison between the SHAMRC and experimental results. First, two of the three measuring locations indicated between a 30 and 40 percent reduction in peak pressure from the free field condition. These gages are located near the front of the structure, the area most likely for soldiers to occupy, and provide good indications of survivability level increases inside. The third gage, located at the back wall, indicated a slight increase in peak pressure from the free field. Note that this gage is very close to the rear "free air" gage depicted in Figure 6, which shows the same trend. The differences in peak pressure between the front and back are caused by wave reflections and wave interaction. As the structure is engulfed, the shock front is propagating through the main structure cavity and collides with the shock entering and reflecting from the rear of the structure. This is evidenced by a closer examination of the rear gage in Figure 6, which shows an initial peak of only 4 psi, but then gives way to a more sustained 9 psi pressure level later in time.

With regard to impulse, as is always the case with shock wave propagation through structures, reductions in peak pressure should be expected, as should increases in duration. Two of the measuring locations, the wall and floor gages, indicated this. As seen in Figure 2, the top portion of the structure is generally open and the lower portion of the structure is generally closed. The wall and floor gages were located in the lower portion of the structure, and thus should have been expected to experience increased pressure duration as the waves reflected off the inner wall surfaces. However, in contrast the free air gage experienced an approximate 35 percent reduction in impulse. This stands to reason since it was located nearer the top portion of the structure and will be less impacted by surface reflections.

To give an example of the vulnerability assessment that may be extracted from this information – which is the ultimate objective of the entire program - it can be concluded that in the front portion of the structure the peak pressures were

significantly less than those which would be experienced in the free field at the same standoff. Also, in these same areas it will be possible to experience reductions in peak impulse, but it may be more appropriate to assume that the impulse matches that of the free field. From this, with a decrease in peak pressure and non-changing impulse the hazard potential to occupants in the front of the structure should decrease – thus enhancing the degree of survivability. Concerning the rear of the structure, based on the assumed bomb location and structure configuration the hazard level would not have decreased as much as the front. It is important to note that the occupants were not exposed to an increase in threat level, simply the structure did not increase their survivability level to the degree of those in the front. Therefore, to further enhance the structure's performance it would be reasonable to consider modifications that disrupt the phenomenon creating these conditions and improve the pressure environment in the rear.

The second observation to be made concerns the comparison between the results of SHAMRC and the physical model. Very good agreement was seen between both the magnitude of peak pressure and the wave form. This is of special note considering all of the variables that can impart deviations between a numeric and physical model. The floor gage showed nearly an exact match in peak pressure, and the "free air" and wall gages did not show more than a 12 percent deviation from experimental. Concerning impulse, in all cases SHAMRC slightly under-predicted peak values. However, the under-prediction only ranged from 13 to 15 percent. Based on these comparisons, it can be estimated that the hydrocode method of predicting internal conditions will yield reliable results.

4. FULL SCALE VALIDATION

To fully validate results of the numeric and scaled simulations, it is necessary to conduct key full-scale experiments. At completion of this research initiative, it would be desirable to have conducted at least one validation for each structure. However, due to resource requirements only one full-scale validation has been conducted to date. Results of the experiment are presented below.

In May 2004, ERDC participated in the 2004 Australian international Defence Trial No. 845. The trials, conducted in Woomera, Australia, were jointly sponsored by the Australian Ordnance Safety Group and the United Kingdom Defence Ordnance Safety Group. As a part of the activities, an arena type experiment was conducted in which participant structures were exposed to the effects of a multi-ton high explosive charge. ERDC structures included in the experiment were from the Hesco Bastion based family of positions, and included a personnel bunker, a fighting position and a small observation post. The large observation post, for which data was presented in Sections 2 and 3, was not included in the experimental array and is therefore not available for comparison. However, the small observation post that was included in the trial was also modeled in the scaled

experiments and will therefore be utilized to show a comparison between the scaled and full-scale results.

As with the large observation post, the small observation post scaled experiments were conducted with a charge size chosen to simulate a car bomb explosion. However, due to the parameters established for the Australian trial the charge in the scaled experiments did not scale to match that in the full scale. Furthermore, the explosive material utilized in the two experiments differed. To resolve this, it was determined to place the full-scale structures at an appropriate standoff to generate the same impinging peak pressure as was seen in the scaled experiments. With impinging pressure viewed as the common "driver" between the two experiments, comparisons could then be made between peak internal pressures. It is recognized that although peak impinging pressures can be closely matched, the wave forms and impulses will still not be the same for the two charges. However, the trial was deemed a viable opportunity to gather full-scale data and it was felt that validation could be performed through observation of the internal peak pressure trends.

The small observation post has overall dimensions of 8 ft by 12 ft, and is more closed with regard to window openings than the large observation post. In the Australian trials, the structure was instrumented with only four overpressure gages due to data acquisition limitations. Three of these gages were placed on the interior near the front of the structure. Two of the gages were placed approximately 60 in. above ground – near chest height – and one was placed 24 in. above ground. These closely matched gage locations used in the scaled experiments. A picture of the small observation post, along with the other ERDC structures, is shown in Figure 16.

Figure 16. Defence Trial No. 845 experimental setup

Scaled modeling of the small observation post was conducted in much the same manner for the large observation post. The position was exposed to a Composition C-4 charge at set standoff, and the resulting pressure environment was measured with an array of twelve gages. Thirteen explosions were conducted, one of which was placed directly in front of the structure.

Presented in Figures 17 and 18 are comparisons of pressure-time histories for two gages from each experiment. One pair were "free air" gages mounted near the front of the

structure and the other were a pair of gages mounted near the floor. Because of the different charge sizes and standoffs used, two data adjustments were made to facilitate the comparison. First, the time of arrival for the shock front will clearly differ between the two experiments. Therefore, the data from the scaled experiment was shifted in time such that the arrival times matched for both experiments. Second, since by definition all components of the scaled experiment were scaled, the time component of all data points were scaled by the scaling factor to generate a pressure duration that could be compared to the full-scale results.

As with all other data, the pressure records have been normalized to generate free field values of 10 psi.
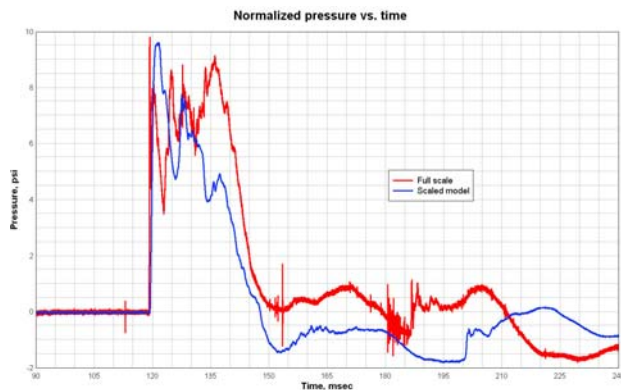
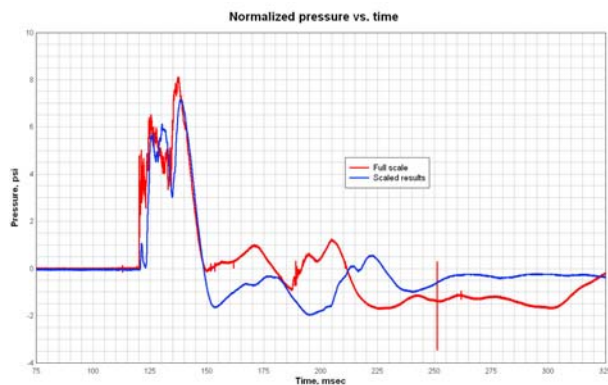Figure 17. Free air gages, comparison of full-scale & scaled

Figure 18. Floor gages, comparison of full-scale & scaled

As seen, reasonable agreement was found between the results of the full-scale and scaled experiments. This is true for both peak pressure and wave form, although the latter is not of significance considering the factors previously discussed. From this, indications are that the use of scaled modeling in this scenario is a viable option to predict pressure conditions in the full-scale environment. Although this is true, it should be noted that some data did not show the same close agreement, and therefore additional full-scale experimentation is warranted before the correlation between these methodologies can be made conclusive.

CONCLUSIONS

The ultimate objective of these efforts is to support the development of computational capabilities that can be used to perform rapid vulnerability assessments of field fortifications for US expeditionary forces. To accomplish this objective, a sub-set of research tools must be developed to generate the information required to support the assessment program. At the heart of these tools must be high-performance computing simulations, which are subsequently supported with physical experimentation such as scaled and full-scale modeling. With this full spectrum approach to consideration of tremendously complex conditions, an efficient and cost effective means of arriving at the answer can be employed.

ERDC has initiated preliminary efforts in all three areas of the research program. The intent of these efforts was to gather representative data from each simulation component and then evaluate and compare the results to determine if they meet the program needs. In all areas, good comparison was found between the three evaluative methods. The internal conditions predicted by SHAMRC, for both pressure and impulse, were found to be in very close agreement with the scaled model. From the data considered, only a 12 percent deviation was found in peak pressures, and a maximum of 15 percent deviation was found in impulse. Close correlation was also found between scaled modeling and full-scale evaluation of the small observation post. In the full-scale experiments, although wave form and impulse could not be compared the trends in peak pressure reductions closely matched.

With these results considered, the probable next phase of the project will be to perform a final series of comparative experiments to conclusively validate accuracy of the process. In this case, a full-scale structure should be modeled in SHAMRC, compared to the results of scaled model experiments, and then finally included in a full-scale validation that directly mimics the SHAMRC configuration.

As an organization involved in military research, it is important to always recognize the balance that must be maintained between improvements for the future and support to current warfighter needs. Researchers must be watchful for any intermediate products or advancements that could be of immediate use to the warfighter. In this case, these viable pieces of information are in the form of basic survivability assessments that can be derived from the experimental data (as shown in the discussion of results from the large observation post scaled experiments). This type of information can be, and has been, extracted from the experimental data to provide critical information to warfighters who are faced with this type of scenario.

ACKNOWLEDGEMENTS & DISTRIBUTION

MODELING & MITIGATION OF BLAST EFFECTS WITHIN PROTECTIVE STRUCTURES

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Sponsoring Program & Objective

• Research conducted as a part of STO IV.EN.2002.03 "Protection Against Terrorist & Conventional Attacks in Contingency Environments"

• Objective – Enhance force protection capabilities of expeditionary forces by developing an **analytical tool to predict blast hazards to field fortifications**

Camp Bondsteel, Kosovo
March 2000

Problem

Considering car bombs as a probable threat, significant work has been conducted to analytically evaluate the vulnerabilities of conventional structures

Today's 360° battlefield has moved the enemy threat from the historical " battle front" to our basecamps and rearward operating areas

However, blast effects on field fortifications employed by expeditionary forces poses a new arena of consideration

MODELING & MITIGATION OF BLAST EFFECTS WITHIN PROTECTIVE STRUCTURES

Field Fortifications

• **Short to medium-dwell structures**

• **Initial efforts will focus on Hesco Bastion protective positions; Four included in initial evaluation**

• **Due to structure mass, the internal pressure-impulse environment is assumed as the controlling hazard to occupants**

• **Structural failure in response to dynamic loads will occur only after internal conditions have surpassed lethality level**

Belowground personnel bunker

Aboveground personnel bunker
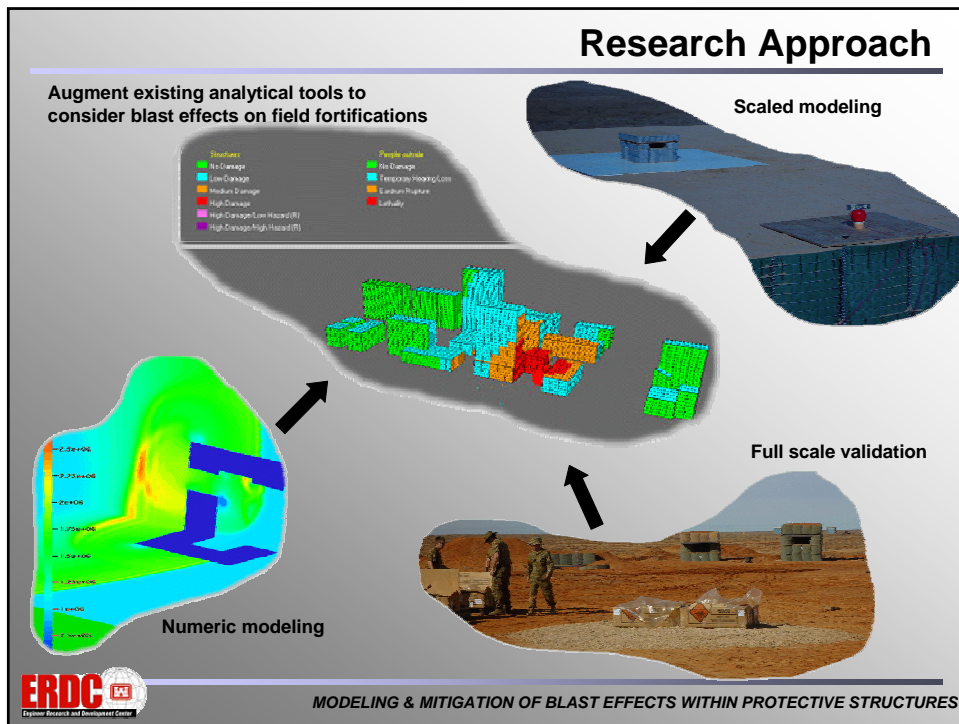
Large observation post

Small observation post

MODELING & MITIGATION OF BLAST EFFECTS WITHIN PROTECTIVE STRUCTURES

Research Approach

Augment existing analytical tools to consider blast effects on field fortifications

Scaled modeling

Full scale validation

Numeric modeling

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FY 04 Efforts

- Select data sets developed for each experimental component (numeric modeling, scaled modeling, full scale validation) to compare results and validate approach

- Efforts include:

Scaled modeling of the four selected positions

Full scale validation of small observation post

Numeric modeling of large observation post

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Numeric Modeling

• **For cost effectiveness and efficiency, numeric modeling will be the primary mechanism for data generation**

• **Utilize SHAMRC (Second-order, Hydrodynamic, Automatic Mesh Refinement Code) as calculational tool**

• **Initially model large observation post**

• **Model the structure at 1/8th scale to provide direct comparison to scaled model**

• **Modeling scaled conditions provides most direct comparison to physical experiments, and if agreement is found then only Hopkinson's scaling laws must be applied**

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Numeric Modeling

• **SHAMRC output generated in two forms**

  ✓ **Animation of shock flow**

  ✓ **Graphic pressure-time histories for point-specific locations**

• **Output in these forms supports general characterization of internal environment as well as insight into shock flow phenomena (reflections, wave interaction & coalescence, etc.)**
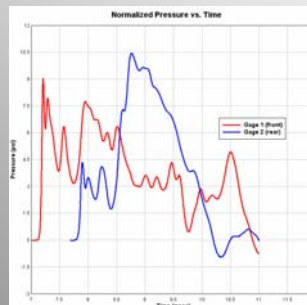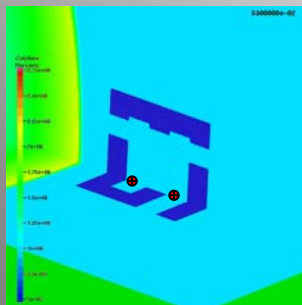
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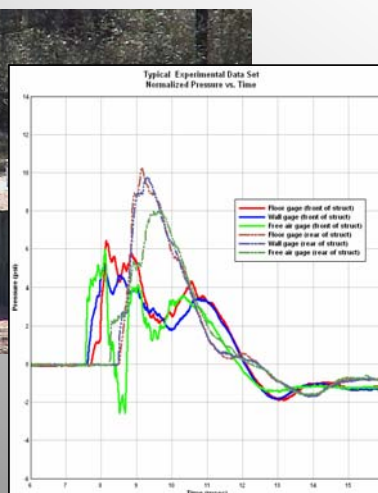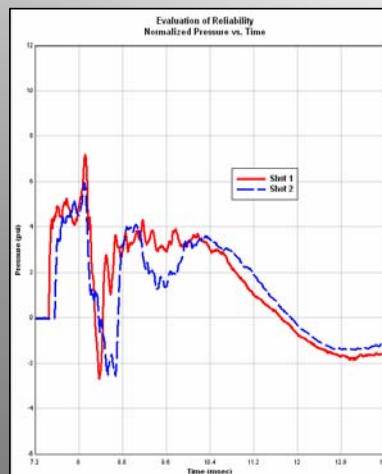## Scaled Modeling

- **Experimental parameters:**

  ✓ **4 structures modeled**

  ✓ **Model scale = 1/8th**

  ✓ **Model sizes ranged from 12"x18" to 75"x44"**

  ✓ **Each structure instrumented with 12 to 14 overpressure gages**

  ✓ **Each structure exposed to between 7 & 16 explosions at differing azimuth and range**

  ✓ **100-200 pressure-time histories collected for each structure**

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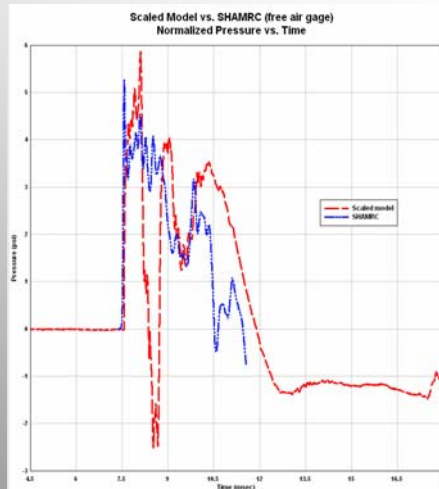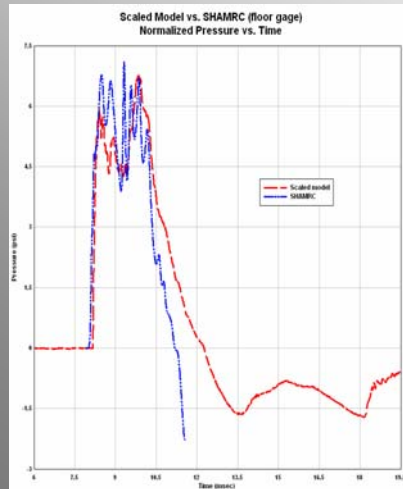

Scaled Modeling

Experimental results

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Scaled Modeling

Comparison to SHAMRC

Full Scale Validation

• **Necessary to validate numeric and scaled model results**

• **Small observation post validated in Australian/UK Defence Trial No. 845, Woomera, AU, May 2004**

• **Based on trial parameters, charge size and explosive material did not directly correlate to scaled models**

• **To make comparison to scaled results, standoff chosen to generate same peak impinging pressure**

• **Although wave form differs, comparisons can be made based on internal pressure peaks**
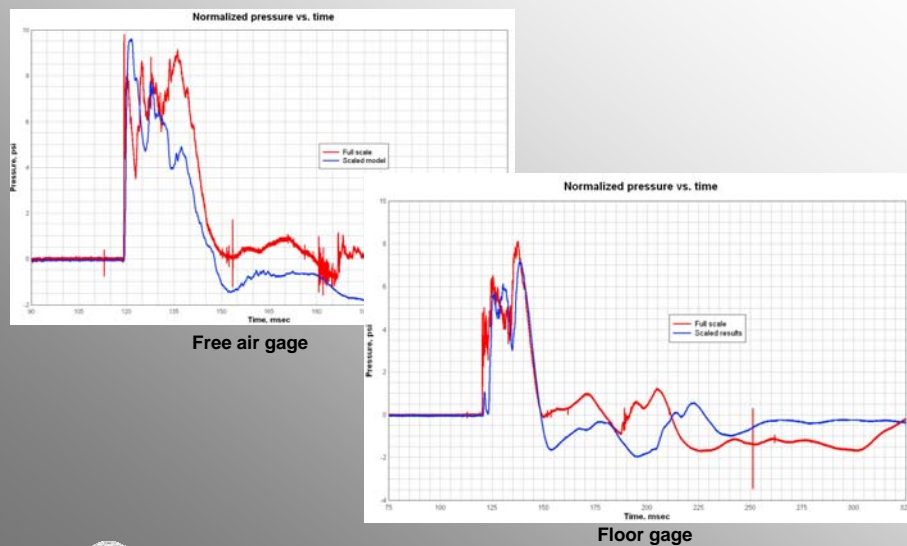
Full Scale Validation

Experimental configuration

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Full Scale Validation

Comparison to scaled results

Free air gage

Floor gage

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Analytical Algorithm

- **Once data sets are validated, how can they be used to develop an analytical algorithm?**

- **Solution - response surface**

- **Response surface – Statistical evaluation of data that can be used to establish relationship between multiple variables; Results in mathematical expression of correlation**
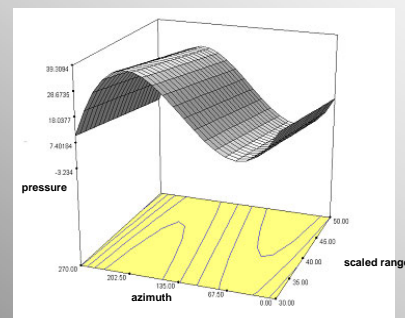

Analytical Algorithm

Response surface example

- **8 shots, 2 in each cardinal direction**

- **Independent variables – scaled range & azimuth**

- **Dependent variables – internal pressure & impulse**

Azimuth	Z	Pressure	Impulse
0	30	23	54
0	50	10	25
90	30	12	28
90	50	4	10
180	30	40	76
180	50	25	40
270	30	10	20
270	50	2	5

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Objective Restatement, Accomplishments & Conclusions

Objective – Enhance force protection capabilities of expeditionary forces by developing an analytical tool to predict blast hazards to field fortifications

Accomplishments –

✓ **Preliminary data set developed for all three experimental thrusts**

✓ **Good agreement found between SHAMRC model of scaled experiment and scaled physical model for large observation post**

✓ **Good agreement found between scaled model and full scale validation for small observation post**

Conclusions –

✓ **Approach is valid and is supported by experimental data**

✓ **High performance, hydrodynamic codes will be the most effective means of further data generation**

✓ **Additional full-scale experiments are required for final validation**

Camp Bondsteel, Kosovo
March 2000

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